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# Forensic Investigation of a Failed Intermediate Starwheel Spur Gear Tooth in a Filler Machine

Enesi Y. Salawu*, Oluseyi O. Ajayi, A.O Inegbenebor,

[a]*Department of Mechanical Engineering, Covenant University, P.M.B 1023, Ota, Ogun State, Nigeria*

**Abstract**

Forensic investigation of failed engineering component involved the applications of engineering methods and techniques to determine the root cause of failure and how to prevent subsequent failures. Thus, the study focused on the analysis of a failed intermediate star wheel spur gear tooth using metallographic observations. Three (3) different failed gear teeth were selected and prepared as metallographic samples. Each of the samples were observed under the optical microscope at different magnifications, ranging from 10, 40 and 100 µm. Further to this, the samples were subjected to visual observation. The result obtained from the microstructures were further analysed using 3D surface analyser. The result of visual observations revealed the presence of wear debris around the failed teeth, while the optical micrographs depicted the occurrence of pitting corrosion, Also, observed were regions that show zones of high stress raisers. The results from the 3D surface analyser further demonstrates the occurrence of variation in wear distribution with some zones under higher intensity of material erosion. This may be due to the presence of backlash during the meshing of the gears. The pattern of the results is therefore suggestive of the fact that the gear material was not properly matched with the operation environment. The study also looked at the economic effect of the downtime which the gear failure poses on the productivity of the filler machine.


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*Keywords:* Fatigue Failure, Fracture Mechanics, Reliability, Spur Gear, Production

*Corresponding Author: enesi.salawu@covenantuniversity.edu.ng

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## 1. Introduction

Wide application of gears in power transmission have become an art and science of great importance and this is attributed to its higher efficiency over belt drive. However, the failure rate of gears cannot be overemphasized and this has become a critical area of focus for most researchers [1]. For instance, study has revealed that the peak effective stress occurred at top land of spur gear tooth and this is transferred circumferentially down to the interior of the gear material. This maximum stress usually results to high temperature which are distributed in a nonlinear behavior on the gear tooth, making this material susceptible to fatigue failure [2]. Deficiency in the design of the involute tooth of spur gear lead to poor efficient transmission [3]. Consequently, leading to crack propagation which can be detected by finite element technique [4]. Further studies of gear failure revealed that, on-line particle monitoring technique via lubricating oil is effective in revealing macro pitting failures on the tooth surface of gears, but this has not been an effective method of preventing the gear failures [5]. Furthermore, minimum backlash and better damping coefficient through parameter variation were identified as methods of improving the structure and reliability of planetary gear systems [6]. Various forensic studies to investigate the failure of gears have been carried out in the past. For instance, the cooler fan driving a helicopter showed that failure resulted due to fatigue/ shock loads and this happened with different mode. This fatigue cracks are mostly formed at the root of the gear tooth while in service and one way to reveal this failure is by etching [7]. Critical study of the crack propagation root relative to the angles of propagation will help in predicting the fracture failure and this will enhance the gear design life [8]. According to [9], hardening of the surface, proper tolerance fit and interference fit are fundamental factors which can improve wind turbine gear design. Study has showed that the effect of overload of planetary gear in highway axle lead to misalignment of the gear tooth and the brittleness of the material resulted in sudden crack propagation which eventually lead to complete fracture failure [10,11]. Further research on failure prediction has been carried out. For instance, application of dynamic model to predict the vibration, mesh stiffness and behavior of the gear tooth have been useful tools in predicting gear failures [12,13]. However, proper choice of materials, manufacturing methods, operating strength as well as areas of application during gear design helps in improving the reliability of the system [14, 15, 16, 17, 18, 19, 20]. The aim of this study was to carry out a forensic analyses of the root cause of failure of the intermediate star wheel spur gear using the optical microscope in order to reduce the increased machine downtime and to establish the importance of this method over the other techniques of analyzing failures of spur gears in machine.

## 2. Experimental procedure

The failed gear tooth was obtained and cleaned for sample preparation. Secondly, metallographic samples were prepared by sectioning the visually inspected failed region which is the area of interest of the failed component. The metallographic samples were sectioned carefully to avoid structural destruction using hacksaw. Different magnifications ranging from 10, 40 and 100 μm were used to obtain the best image which revealed the micro structures of the various tested samples. Omax trinocular metallurgical microscope was employed in this research work. Fig.1, represent the pictorial view of the failed gear component, while fig. 2 presents the microscopic images from the optical microscope.

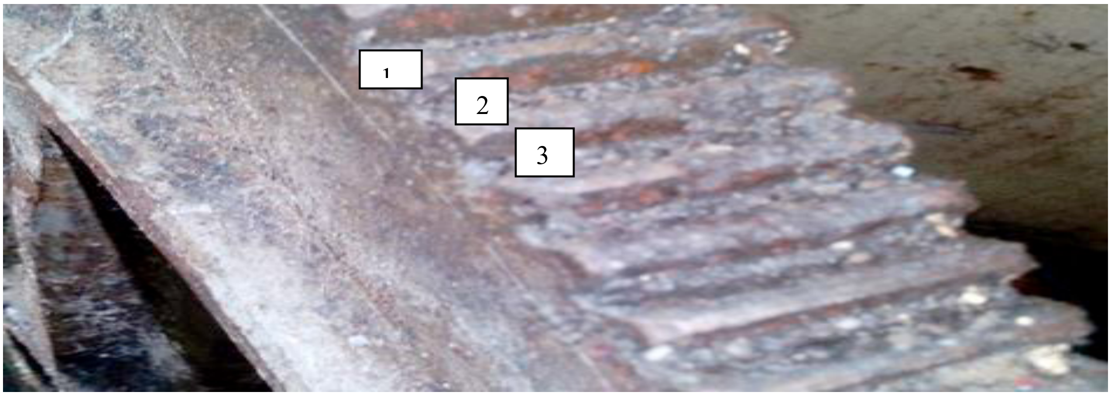
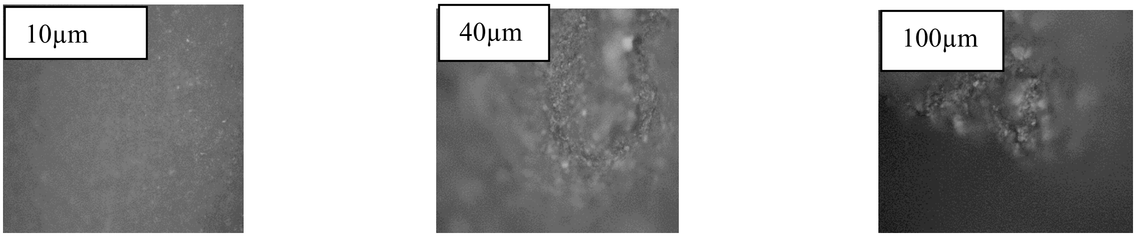



Fig.1. Pictorial view of the failed intermediate spur gear tooth

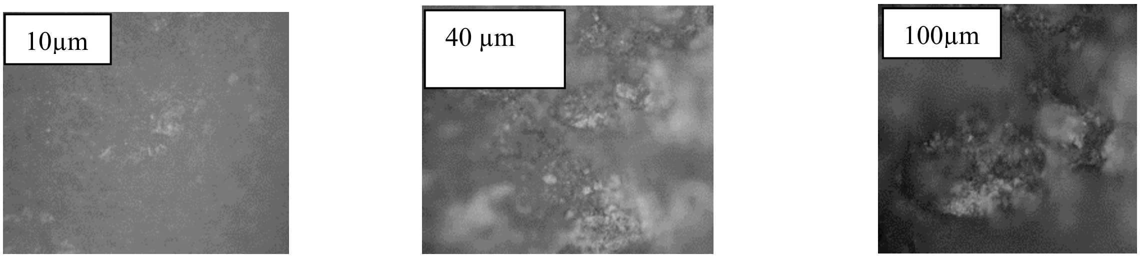
## 3. Results

### *3. 1. Optical micrograph*



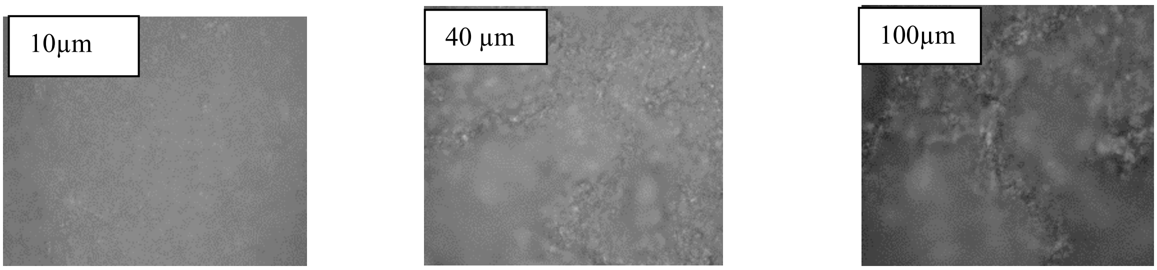

a b c

Fig.2. Tooth 1




d e f

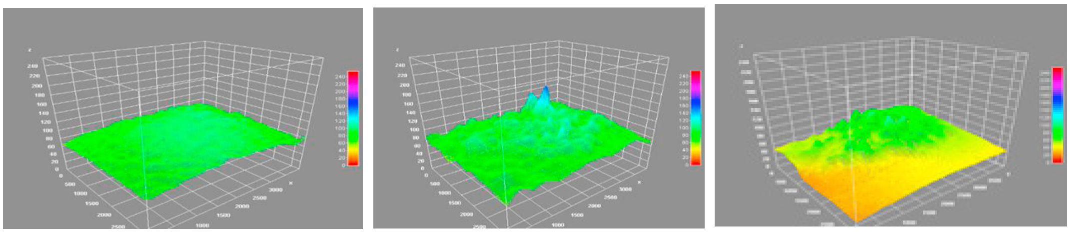
Fig.3. Tooth 2




g h i

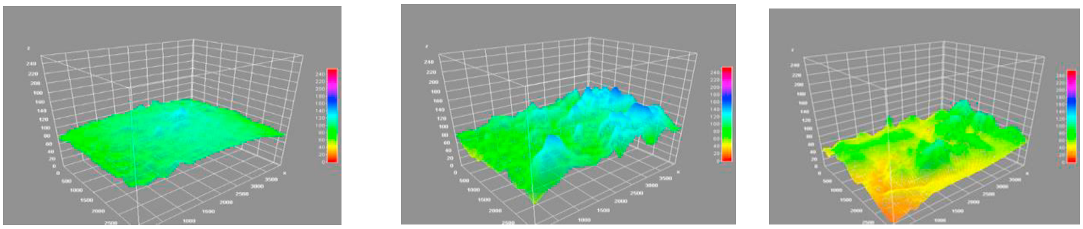
Fig.4. Tooth 3

*3.2. Result of 3D Surface Analyzer*



a b c

Figure .5. Tooth 1



d e f

Fig .6. Tooth 2

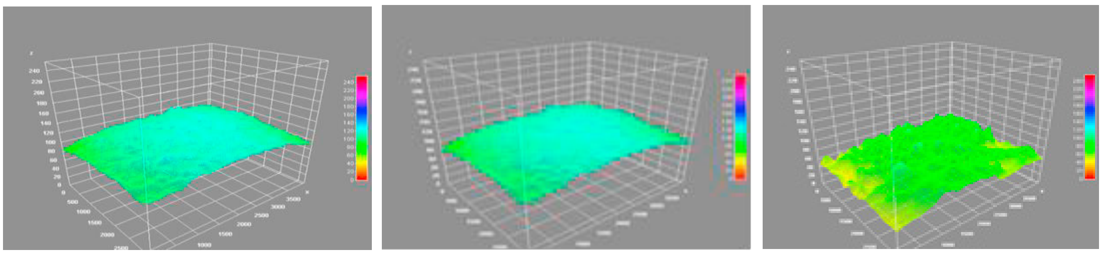


Fig .7. Tooth 3

**4.0 Discussion**

*4.1. Analysis of the optical micrographs*

Figures 2a-c, represents the micro structures of the failed gear sample labelled as tooth 1. The micrographs were taken at different magnifications to reveal the best structure of the failed gear tooth. It can be observed that 40 and 100 magnifications, gave better micrograph structure unlike that of 10. More so inclusions were observed at the tooth surface which may serve as stress raisers for surface deformation. Similarly, figures 3d-f, also presents the optical micrograph for gear tooth sample denoted by number 2. It can be deduced that higher inclusions as well as pitting corrosion were observed at higher magnifications. This eventually led to crack propagations at various point causing incessant failure of the gear component. On the same hand, figures 4g-i, also revealed the micro structures of the gear tooth number 3. Though failure here is not as severe as that of the one noticed on the gear tooth labelled as 2. However, presence of inclusions on the surface asperities had brought about unevenness in the surface roughness there by leading to gear tooth failure.

*4.2 Surface Topography Result Analysis*

Figures 5a-c presents the 3D surface plot of the optical micrograph result for tooth 1. Variations in the valleys and peak from the plot showed the failure as well as stress distribution pattern. It is worthy of note to say that figure 5c showed the highest variation in wear pattern which can be attributed to increased misalignment of the tooth.

Similarly, figures6d-f also presents the 3D surface plot for the micrograph of tooth2. Figures 6d and 6f gave a better result of the wear distribution on the surface of the tooth with 6f showing the highest variations in valleys and peak owing to the fact that the magnification considered was higher (100 mag). More so, figures 7g-i also represent the 3D surface plot for the different micrograph of tooth 3. It was observed that variations in the wear pattern was higher for figures 7h and 7i. However, figures 7i presented an increased wear pattern on the gear tooth which is due to persistent tooth misalignment. The significance of the wear behaviour of the investigated gear teeth is that gear misalignment was responsible for the variation in the wear pattern and this justifies incessant failure of the gear tooth.

## Conclusion

Forensic investigation of a failed intermediate star wheel spur gear has been carried out using optical microscope. Critical examinations of three (3) failed gear teeth were carried out using the optical microscope at 10, 40 and 100 magnifications to reveal the micro structures. Variations in wear behaviour were observed at different magnification for each tooth. These variations in the wear behaviour were more alarming from the result of the surface topographies. Thus, it is worthy of note to say that the wear behaviour of the failed teeth is due to repeated cyclic stress on the surfaces which caused continuous tooth misalignment. Consequently, increased misalignment resulted in total tooth failure. Therefore, optical metallography is useful for failure investigation Further research can be carried out on the crushing stress which lead to complete tooth failure.

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